Exploring habitability under superflares when the ozone layer formed on Earth (Poster Flash Talk)

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Introduction

Kepler-96 is a solar analogue star harbouring a Super-Earth planet in close orbit. Its age of 2.3 Gyr is the same as the Sun when there was a considerable increase of oxygen in Earth's atmosphere in the end of the Archean era due to micro-organisms living under the sea. This star is still very active and has several superflares on its lightcurve. Some authours (Airapetian et al (2016), Manasvi and Loeb (2017)) discussed about the possibility of such superflares occuring in the young Sun and their impact on the primitive Earth. Thus, Kepler-96 is an interesting target to study the Archean Earth conditions if the Sun have had such superflares at that time.

Goal

The goal of this work is to analyze the biological impact of Kepler-96 superflares (seen on the transit lightcurve of Kepler-96b) on the close by planet and also to an hypothetical Archean Earth-like planet in the habitable zone (HZ) of this star.

Methods

Our analysis is based on the four years of continuous short cadence observation of the star by the Kepler telescope. The model used here simulates a planetary transit and allows the insertion of a flare in the stellar disc with different size, amplitude, and position. By fitting the observational data with this model, it is possible to infer thephysical properties of the flares. The model fitting of the flare peaks seeing during the transit yields the estimate of the duration (few minutes) and energy released by each flare.

Afterwards, we analyse the increase of the MUV surface irradiance flux due to the superflares under different atmospheric scenarios adopted from Cnossen et al (2007): an Archean atmosphere and a Present day atmosphere with ozone. To estimate the UV flux contribution of the Kepler-96 flares, we used the UV flux measured on the most intense solar flares observed. Woods et al (2004) reported one of the largest flares found in the Sun, a X17 GOES class flare with total energy of $E = 4 \times 10^{32}$ ergs, that increased by 12% the solar MUV flux. As the total thermal blackbody flux of Kepler-96 and the Sun are very similar, we considered that the superflares found in Kepler-96 would increase the UV flux proportionally.

Then, we estimated the biological impacts that the MUV flux of the strongest superflare found here could have in Kepler-96b and in a hypothetical Earth in the HZ either for life on the planet surface or under the ocean. In both cases, we analysed the increase in the MUV flux due to the superflares by weighting it with the DNA action spectrum know as biological effectiveness irradiance (E_{eff}):

(1)

where F_{inc} is the total incident MUV flux with the superflare contribution arriving at the planet surface/ocean depth, S is the DNA action spectra and λ is the MUV wavelengths.

For the ocean, the propagation of the UV radiation in the varies considerably with depth, and can be determined by the equation:

(2)

where $I(\lambda, z)$ is the UV spectral irradiance at depth z, $I_0(\lambda)$ is the UV spectral irradiance with the superflare contribution passing through an Archean atmosphere and $K(\lambda)$ is the diffuse attenuation coefficient for water. Then, we verify if the MUV flux received by the biological body present in these planets can be tolerated by microorganisms that define the surviving zone for life such as Deinococcus radiodurans and Escherichia coli.

Results

We estimated the E_{eff} for an Earth-like planet in the HZ of Kepler-96 and for the super-Earth Kepler-96b. The threshold for the E_{eff} was chosen using two microorganisms that define the surviving zone for life: Deinococcus radiodurans and Escherichia coli. The maximum UV flux for 10% survival for D. Radiodurans is $F_{10}^{UV}= 5.53 \times 10^2$ J/m^2 (Ghosal et al, 2005), while for E. Coli is $F_{10}^{UV}= 22.6$ J/m^2 (Gascon et al, 1995).

For the contribution of the strongest superflare found (increase of 5430% in the MUV flux), the biological effective irradiance shows that D. radiodurans would only survive on the surface of Kepler-96b and of a hypothetical Earth at 1AU if there is an ozone layer present on the planet atmosphere (see Table 1).

Biogolical Effective Irradiance (Surface), E_{eff} [J/m^2]		
Planet	Archean atmosphere	Present-day atmosphere
Kepler-96	3.4×10^7	178
Planet at 1AU	1.6×10^4	0.0084

Table 1: Biologically effective irradiance for DNA damage at the surface of Kepler-96 and of a Earth-like planet at 1AU.

Moreover, we also analysed the ocean depths that could harbour extremophile life in Kepler-96 planets without being damaged by the strongest superflare found in Kepler-96 (see Table 2). Although Kepler-96b and a hypothetical Earth-like orbiting Kepler-96 receive an increased UV radiation due to the superflares, life could still survive in depths inside the photic zone (up to 200m) of an Archean ocean present in these planets.

Biogolical Effective Irradiance (Ocean), E_{eff} [J/m^2]		
	Ocean depth	
Planet	E. Coli	D. Radiodurans
Kepler-96	48m	35m
Planet at 1AU	20m	8m

Table 2: Biologically effective irradiance for DNA damage with depth in an Archean ocean present in Kepler-96b and in a Earth-like planet at 1AU. The ocean depths found are those receiving the maximum UV dosage that E. Coli and D. Radiodurans could support.

Conclusions

The conclusion is that life would only survive on the surface of Kepler-96b if there was an ozone layer present on the planet atmosphere. Life could also support the effects of the strongest superflare in this planet if it was at a depth of below 48m the ocean surface. For a hypothetical Archean Earth, life can be sustained only in the presence of ozone, considering the effects of the strongest superflare, or at 8-20m ocean depth.

References

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Short Summary

Kepler-96 is a solar analogue with the same age as the Sun when a considerable increase of oxygen in Earth's atmosphere happened. Here we analyze the biological impact of Kepler-96 superflares (seen on the transit lightcurves) on a Super-earth and also on a hypothetical Earth-like planet in the habitable zone of this star.